SECULAR VARIATIONS OF SEMIMAJOR AXIS OF DEBRIS PARTICLES NEAR GEO DUE TO SOLAR RADIATION PRESSURE

M.A. Smirnov, A.M. Mikisha, E.S. Novikova, L.V. Rykhlova

Institute for Astronomy of Russian Academy of Sciences,
Pyatnitskaya 48, Moscow, 109017, Russia, Email:msmirnov@inasan.rssi.ru

ABSTRACT

A study of long-time orbit variations of high satellite orbits due to solar radiation pressure was performed, as well as evolution of debris particle orbits near geosynchronous orbit. Debris particles are involved in all natural processes in the near vicinity of the Earth, including such as solar activity. Only the asymmetry of the scattering field is the cause of secular evolution of the orbit. Such radiation pressure leads debris particles on the geostationary orbit move along non-libration orbits instead to gather around the libration points. This proves the existence of a natural way to clean the geostationary orbit from a part of space debris fragments.

We assume that a bent metallic sheet represents the debris particle. Obtained results showed that sufficient deviation of its semimajor axis occur.

1. THE MODEL OF SPACE DEBRIS PARTICLE

There are many debris particles on the orbits near Earth among them geosynchronous orbits (GEO). The impact of particle with artificial satellite may lead to breakup of satellite. That do the study of debris particles motion and its evolution the important problem for satellite existence.

A detailed study of long-time variations of GEO satellites orbital elements caused by solar radiation pressure was carried out in the Institute for Astronomy, Moscow in [1, 2, 3, 4]. In this paper we consider the orbital evolution of debris particles near GEO caused by the same effect.

The velocity of semimajor axis variations depends of the adopted parameters of debris particles (they shapes, albedo, rotation axis direction etc.). The particle is represented by a metallic sheet of 1-2 mm thickness The albedo is assumed to be 0.15, and the ratio of its effective surface to its mass 1cm^2/g. Main parameters characterizing the shape and the position of the particle in the orbital coordinate system are (Fig.1):

2 α is the angle between the arms of the sheet folded along a straight line;

β_1 is the angle between the rotation axis of the particle and the normal to the sheets folding line in the plane of the bisector of the folding angle;

β_2 is the angle between the rotation axis of the particle and the direction to the orbital pole;

b/a is the ratio of the sheet side values.

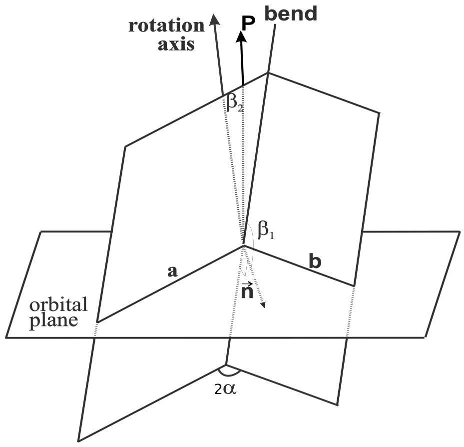

Fig.1. The model of the space debris fragment.

The value of α varies from zero (completely folded sheet) to 90 degrees (flat sheet). Angles β_1 and β_2 vary from zero to 180 degrees. The ratio b/a was considered from 0.25 to 1 for a particle rotating clockwise and from 1 to 4 for a particle rotating counter-clockwise if one is looking from the orbital pole.

2. METHOD OF COMPUTING ORBITAL EVOLUTION

Direct solar radiation pressure does not lead to secular variations of the semimajor axis. Only the asymmetry of the scattering field is the cause of secular evolution of the orbit. This is true even for a circular orbit. According to [1- 4], the evolution of the debris particle

Proceedings of the 3rd European Conference on Space Debris, ESOC, Darmstadt, Germany, 19 - 21 March 2001
(ESA SP-473, August 2001)

orbit is determined by the scattered solar radiation field. The theory of evolution of the debris particles orbital parameters is the same as the theory for GEO satellite. The ten characteristics of the scattering field are determined by photometric observations of the particles. Using these parameters the radiation pressure scattered by the surface of the particle is computated. For the accepted model of particle these parameters are:

$$
\begin{aligned}
B_1 &= \pi \sin\varphi \cdot A \\
B_2 &= \pi \cos\varphi \cdot A \\
B_3 &= \frac{8}{3}\pi \sin\varphi \cdot A \\
B_4 &= \frac{4}{3}\pi \cos\varphi \cdot A \\
B_5 &= -2\pi\left(1-\frac{b}{a}\right)\cos\alpha\cos\varphi \\
B_6 &= 2\pi\left(1+\frac{b}{a}\right)\sin\alpha\cos\varphi \\
B_7 &= -\frac{4}{3}\pi\left(1-\frac{b}{a}\right)\cos\alpha\sin\varphi \\
B_8 &= \frac{4}{3}\pi\left(1+\frac{b}{a}\right)\sin\alpha\sin\varphi \\
B_9 &= -\frac{2}{3}\pi\left(1-\frac{b}{a}\right)\cos\alpha\cos\varphi \\
B_{10} &= \frac{2}{3}\pi\left(1+\frac{b}{a}\right)\sin\alpha\cos\varphi
\end{aligned}
\tag{1}
$$

where

$$
A = \left(1 - \frac{b}{a}\cos 2\alpha\right) + [2\frac{b}{a} - \left(1+\frac{b^2}{a^2}\right)\cos 2\alpha]\times\left(1+\frac{b^2}{a^2}-2\frac{b}{a}\cos 2\alpha\right)^{-\frac{1}{2}}
\tag{2}
$$

Here φ is the angle between the normal and direction to sun (average value during one year). The value of cosφ and sinφ are known functions of β_1, β_2. From above mentioned expressions (1) for the parameters were computed the right sides of differential equations of the particle movement under the pressure of solar radiation scattered by its surface. The evolution was computed for about 500 years for various combinations of parameters characterizing the model of the particle.

3. OBTAINED RESULTS

Computations were performed for following values of the parameters: α = 0, 45, 60, 87, 89 degrees; b/a = 0.25, 0.5, 1, 2, 4. Angles β_1 and β_2 = 0, etc with an interval of 20 degrees. Results of these computations are presented on graphs (Fig.2 – Fig.5).

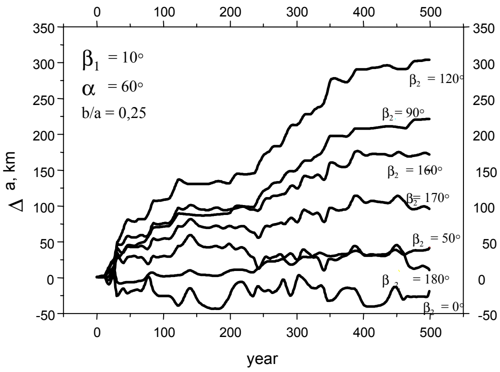

Fig.2. The 500-year evolution of semimajor axis of near GEO debris particle.

Obviously, the evolution of the particles orbit is determined by the deviation (value Δa) of its semimajor axis from the nominal value of the geostationary orbit. Fig.2 shows the 500 years evolution of a particular space debris particle that having values of parameters b/a = 0.25, α = 60 degrees, β_1 = 10 degrees, suffered a change of parameter β_2 from 0 to 180 degrees. As can be seen, in the process of evolution if a space debris particle rotate clockwise the orbit semimajor axis is increasing, while in case of counter-clockwise rotation (b/a = 4) it is decreasing.

The evolution of the orbit of a space debris particle is also clearly illustrated by value Δa/Δt, i.e. the velocity of variation of the semimajor axis. Fig.3 and Fig.4 show the dependence of this value from β_2 for various b/a and α correspondingly. Fig.3 demonstrates the drastic difference of evolution of space debris particle if it rotates clockwise (b/a less unit) and counter-clockwise (b/a more unit). At that in case b/a is small velocity value increase but in case b/a is big the velocity value decrease.

Fig.4 shows that if the sheet is vastly open (α near 90°) then the evolution of the space debris particle orbit will proceed more slowly in contrast with the case α is small.

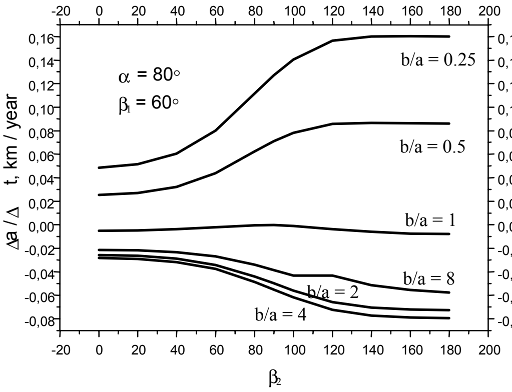

Fig. 3. The velocity of semimajor axis variations as function β_2 (for fixed α and β_1 and different b/a).

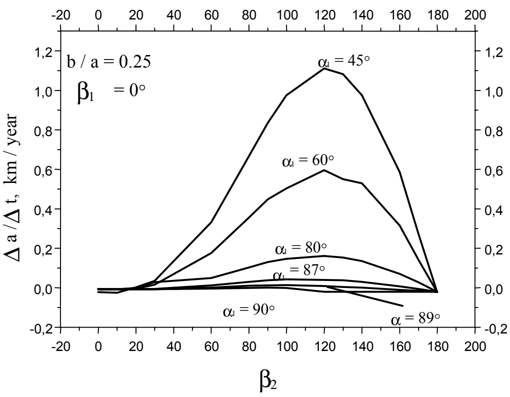

Fig.4. The velocity of semimajor axis variations as function β_2 (for fixed β_1 and b/a and different α).

Fig.5 reveals that the family of curves $\Delta a/\Delta t = f(\beta_1, \beta_2)$ has point corresponding to $\beta_1 = \beta_2 = 90$ degrees through they all pass. This kind of symmetry is clearly seen from the Eqs.1,2. What concerns the line $\beta_1 = 90$ degree passing through this point, there exists a specular symmetry with $f(\beta_1, \beta_2) = f(\beta_1, 180 - \beta_2)$. Fig.5 demonstrate the case of a very opened sheet ($\alpha = 80$ degree) and small value of b/a (b/a = 0.25). To understand the behavior of evolution curves in different cases we need to combine all parameters in all considered cases: Fig.3, Fig.4 and Fig.5. This picture will be four-dimensional for the case when we fix one parameter namely b/a and for other parameters α, β_1 and β_2 should be assumed all possible values.

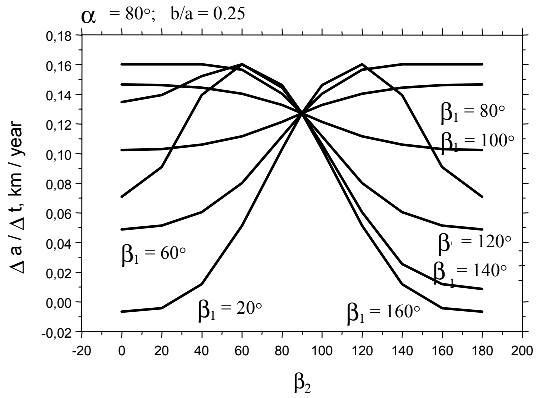

Fig.5. The velocity of semimajor axis variations as function β_2 (for fixed α and b/a and different β_1).

4. CONCLUSIONS

Computations of orbital evolution of debris particles near GEO caused by reflected solar radiation during long time intervals (500years) were made.

Direct solar radiation pressure does not lead to secular variations of the semimajor axis of the particles orbit as has been proved by Celestial Mechanics. Only the asymmetry of the scattering field is the cause of long-time orbit evolution. This is true even for a circular orbit. The perturbations caused of this type radiation pressure leads to particular kind of debris particles orbit evolution. The debris particle on the geostationary orbit move along non-libration orbits instead to gather around the libration points. This effect acts especially strong for small fragments having a rather low ratio of effective surface to mass.

There is drastic difference of orbital evolution of space debris particle if it rotates clockwise (b/a less unit) and counter-clockwise (b/a more unit). It is shown that if a space debris particle rotate clockwise the orbit semimajor axis is increasing, while in case of counter-clock rotation it is decreasing. At that in case b/a is small value of velocity of semimajor axis variations increase but in case b/a is big this value of velocity decreas.

Our consideration proves the existence of a natural way to clean the geostationary orbit from a part of space debris fragments.

5. REFERENCES

1. Mikisha A.M., Smirnov M.A., Determination of the Light-pressure Vector from Photometric Observations of Geostationary Satellites, *Soviet Astronomy*, Vol. 34, pp. 552-558, 1990.

2. Smirnov M.A., Mikisha A.M., Secular Evolution of Geostationary Objects Caused by Light Pressure, *The Technogeneouse Space Debris Problem*, Kosmosinform, Moscow, pp. 126-142, 1993.

3. Mikisha A.M. and Smirnov M.A., Secular Evolution of Space Bodies on High Orbits due to Light Pressure, *Collisions in the Surrounding Space (Space Debris)*, Kosmosinform, Moscow, pp. 252-271, 1995.

4. Mikisha A.M., Smirnov M.A., The Influence of Solar Light Pressure to GEO Objects. Evolution Aspects, *Proc. of the Second European Conf. On Space Debris, ESA SP-393*, pp. 323-325, 1997.